Background

The RPV (Reactor Pressure Vessel) of a nuclear reactor is a key issue in its safety assessment. This vessel is a primary loop barrier and contains the nuclear fuel. During reactor operation the RPV is subject to severe conditions (gamma and neutron radiation, temperature gradients), which gradually degrades the vessel. The main damaging mechanism is the material embrittlement due to its exposure to (fast) neutrons. The embrittlement of the RPV is the limiting factor for the lifetime of the reactor. Therefore all modern nuclear reactors are equipped with a set of RPV surveillance capsules containing representative steel specimen (to investigate the material degradation) and neutron dosimeters (to determine the neutron exposure responsible for the degradation). The capsules are introduced close to the RPV before the reactor start and dismantled and analyzed on a regular basis during its lifetime.

Reactor dosimetry thus aims at determining the neutron fluences that were present at the RPV during the reactor operational lifetime. This information can be obtained from the measured activity of the irradiated neutron dosimeters and the detailed RPV irradiation history (including neutron spectrum calculations).

An important activity in the field of reactor safety is the irradiation of materials. For existing reactors with an inadequate RPV surveillance programme so-called advanced material testing irradiations in high-flux reactors are sometimes required. Also, new types of material or nuclear instrumentation need to be tested in high neutron fluxes for its possible application in next generation reactors. Although neutronic calculations are mostly performed for such experiments, they should always be equipped with neutron dosimeters for an accurate determination of the neutron flux or fluence (time integrated flux).

Objectives

The aim of the reactor dosimetry project is to provide neutron dosimetry services. This includes some or all of following activities:

- determination of the neutron induced gamma- (or X-ray) activity of dosimeters or samples;
- calculation of the neutron flux and fluence at the dosimeter or sample position;
- design and composition of neutron dosimetry sets for new surveillance programmes.

In addition to the services mentioned above, the reactor dosimetry project has some research activities to the requirements imposed by e. g. ageing reactors and new reactor types.

Principal results

The reactor dosimetry laboratory is equipped with six hyper-pure germanium detectors and a central acquisition system. Sample activities ranging from 10^2 Bq up to 10^8 Bq can be measured at the different experimental set-ups. The measurement data are converted to activities, neutron fluxes and fluences using Excel worksheets and in-house developed software taking into account irradiation history and material burn-up corrections. A picture of a detection chain is shown in the figure below.

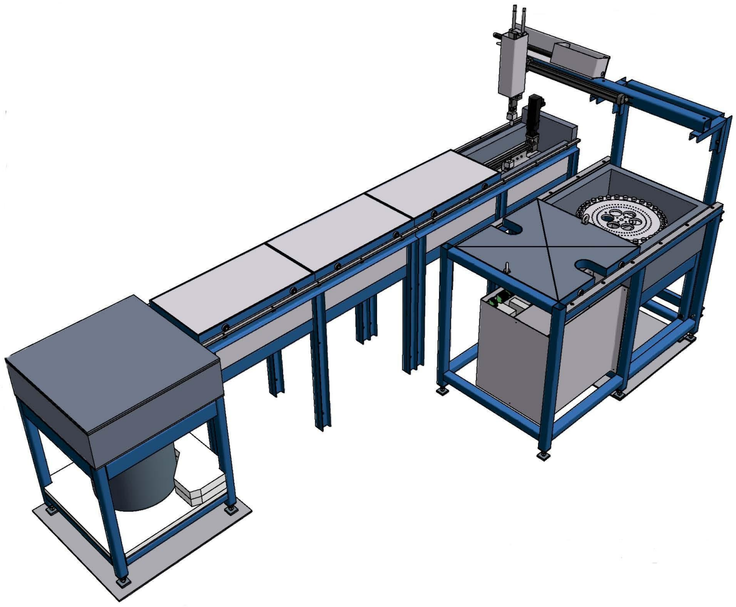
This work is conducted according to ASTM standards. The reactor dosimetry service has been accredited by BELAC (Belgian Ministry for Economic Affairs) under accreditation number 018-T, norms NBN EN ISO/IEC 17025. For the most routinely used materials in reactor dosimetry, a complete file containing measurement and analyses procedures exists to meet the Quality Assurance requirements.

The reactor dosimetry measurements and analyses for the surveillance programme of the Belgian and Spanish nuclear power plants are routinely performed at SCK•CEN. Another important activity is the neutron dosimetry measurements for the irradiation experiments in the BR1 and BR2 reactors, and for the surveillance of the BR2 vessel. In total about 1000 neutron dosimetry analyses are performed per year.

Recent R&D activities were focussed on niobium dosimetry. Niobium is a very favourable material to be used as activation dosimeter: the reaction ^{93}Nb(n,n')^{93m}Nb has a suited threshold of 1 MeV, the activation product ^{93m}Nb has a long half live (16.13 y), and niobium has a high melting point. Thanks to this half-life, niobium is of particular interest for ageing reactors. In addition, niobium sometimes being present in RPV steel or cladding, it is very suited for retrospective dosimetry. The disadvantages of using niobium for this purpose are twofold: (i) pure niobium can embrittle under neutron irradiation; and (ii) the low-energy X-rays emitted during the decay of ^{93m}Nb require special detection techniques. Concerning the latter, suited experimental procedures have been developed and qualified. Concerning the first complication, a 10%NbAl alloy has been developed in collaboration with IRMM and is currently being investigated. Finally, a retrospective dosimetry technique based on niobium was developed in the EC-FP5 project RETROSPEC.

Future work

In order to increase the laboratory efficiency, a fully automated detection system is being developed. Up to thirty dosimeters can be loaded in the holder. This will be a stand-alone system operated with in-house developed software. A drawing of the set-up is shown in the figure below.



In order to meet the neutron dosimetry requirements for future reactor systems, new dosimetry techniques or reactions will have to be investigated, e. g., to determine high energy neutron fluences. In addition, retrospective neutron dosimetry techniques may have to be further explored for the assessment of the oldest RPVs.

Main contact person

Jan Wagemans, jan.wagemans@sckcen.be

Main reference

Reactor dosimetry with niobium, J. Wagemans, L. Borms, M. Willekens, J. Oeyen, A. Moens and V. Kochkin Journal of ASTM International, Volume 3, Issue 2, February 2006.